IV. "The Composition of the Extinctive Atmospheres produced by Flames." By FRANK CLOWES, D.Sc. Lond. Communicated by Professor ARMSTRONG, F.R.S. Received February 7, 1895.

In a former paper ('Roy. Soc. Proc.,' vol. 56), the author communicated the results obtained by mingling gases, which were extinctive of flame, with air, until a flame burning in the air was just extinguished. The gases used in the experiments were carbon dioxide and nitrogen. Each of these gases was separately introduced into the air, and the composition of the atmosphere thus produced, which just extinguished flame, was determined by chemical analysis.

The general results arrived at were:—

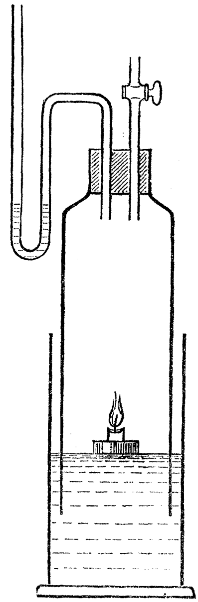
1. That wick-fed flames require atmospheres of very similar composition to extinguish them: while gas-fed flames require atmospheres of widely different composition.
2. That nitrogen must be added in larger proportion than carbon dioxide, in order to extinguish the same flame.
3. That the minimum proportion of extinctive gas which must be mingled with air in order to extinguish a flame is independent of the size of the flame.

A supplementary series of experiments has now been undertaken in order to determine the composition of the atmosphere extinctive of each flame, which is produced by the flame itself when burning in an inclosed volume of air at atmospheric pressure.

Preliminary trials showed that in order to secure trustworthy results, the atmosphere must not be in contact with water. It was further found necessary to avoid change of pressure in the inclosed atmosphere during the combustion of the flame.

These necessary conditions were complied with by allowing the flames to burn in a bell-jar, the bottom of which was closed by dipping into a sufficiently deep vessel of mercury. The neck of the bell-jar was closed by a cork bearing a U-shaped mercury gauge, and a glass tube with a stopcock.

While the flame was burning, the pressure of the air within the bell-jar was maintained uniform by raising or lowering the bell-jar sufficiently to maintain the mercury levels unchanged in the pressure gauge. As soon as the flame was extinguished by the atmosphere around it, the vessel was allowed to stand until the atmosphere within had become uniform in temperature with the air around. A portion of the gases within the bell-jar was then removed by means of the stopcock-tube to a Hempel gas-burette, and was subjected to ordinary



volumetric analysis by absorption. Each experiment and analysis was repeated in duplicate, and frequently in triplicate. The results obtained were either identical or closely concordant, except in the case of methane; but the flame of ethylene could not be maintained under the conditions of the experiment.

The gas was burnt from a tube passing through the mercury and terminating in a jet just above the surface of the mercury. The liquids were burnt from wicks contained in small shallow vessels floating upon the surface of the mercury.

As in the previous series of experiments (*loc. cit.*) the combustible substances used were chiefly those which are burnt for ordinary heating and lighting purposes.

The mean results are tabulated below.

Percentage Composition of the Residual Atmosphere and of the Artificial Atmosphere in which Flame is just extinguished.

Combustible substances burnt.	Percentage composition of the residual atmosphere in which the flame was extinguished.			Proportions per cent. of O_2 and N_2 in which flame is extinguished when introduced.	
	O_2.	N_2.	CO_2.	O_2.	N_2.
Alcohol, absolute........	14·9	80·7	4·35	16·6	83·4
Alcohol, methylated.....	15·6	80·25	4·15	17·2	82·8
Paraffin, lamp oil........	16·6	80·4	3·0	16·2	83·8
Colza and paraffin	16·4	80·5	3·1	16·4	83·6
Candle	15·7	81·1	3·2	16·4	83·6
Hydrogen..............	5·5	94·5	—	6·3	93·7
Carbon monoxide	13·35	74·4	12·25	15·1	84·9
Methane...............	15·6	82·1	2·3	17·4	82·6
Ethylene (failed)........	—	—	—	[13·2	86·8]
Coal-gas	11·35	83·75	4·9	11·3	88·7

In the above table the results are given, which were obtained by the analysis of the residual atmospheres, in which the flame had burnt until it was extinguished. Since the proportions of carbon dioxide contained in these atmospheres are small, the composition of the artificial atmospheres consisting of nitrogen and oxygen only, in which the flames were just extinguished when they are inserted, are also stated for comparison. It will be noticed that the general agreement in composition shown by the two classes of extinctive atmospheres, so differently produced, is well maintained; and when the conditions of the experiments are taken into account the recent series of results are confirmatory of the general accuracy of those previously obtained.

I have to acknowledge the assistance rendered by M. E. Feilmann, B.Sc., in carrying out the experimental work involved in this investigation.

[February 18, 1895.] It is noteworthy that the composition of the extinctive atmosphere produced by the flame of a candle, or of oil, or of alcohol, closely corresponds with the average composition of air expired from the lungs. The composition of the last portion of air which is expired varies somewhat with the length of time during which the air has been retained in the lungs. The following percentage composition by volume was determined :—

Analyses of expired air.	O_2.	N_2.	CO_2.
Air expired immediately after having been inhaled	17·4	78·4	4·2
Air expired about 40 seconds after having been inhaled.........................	14·9	81·4	3·7
Average composition of expired air	16·15	79·9	3·95

According to the statements published by Dr. J. Haldane ('Roy. Soc. Proc.,' December 6, 1894), an atmosphere of the average composition of expired air, or of that left by the combustion of candles or lamps, although it is extinctive of the flames of candles and of lamps, can be breathed by most people without producing any distinctly noticeable effect. With some people, the increased proportion of carbon dioxide would cause the inspirations to be somewhat deeper than usual, but in no case would injury to health result from breathing such an atmosphere.

The statement made by the author in a previous paper ('Roy. Soc. Proc.,' vol. 56), that men could apparently breathe with safety an atmosphere which just extinguished the flame of a candle or of a lamp, is therefore fully borne out by the above results. This agrees with the statements made by experienced mining authorities. Accordingly the extinction of such ordinary illuminating flames cannot be considered as proof that an atmosphere is not respirable with safety.

The residual atmosphere produced by the hydrogen flame is undoubtedly not respirable, on account of the greatly diminished proportion of oxygen which it contains. The colour of the hydrogen flame undergoes a distinct change in colour from reddish-purple to blue as the proportion of oxygen in the atmosphere is diminished. Since a similar change of colour is noticed when carbon dioxide is present in the atmosphere, it is probably due to the lowering of temperature of the flame: all attempts to detect the production of carbon monoxide by this flame, when it is burning in air containing carbon dioxide, have failed.

The conclusions which may be drawn from the above results are that:—

1. The flames of the combustible gases and liquids, which were experimented upon, produce, at the point of extinction in an enclosed atmosphere, a change in the proportion of oxygen in the air generally corresponding to that produced by preparing extinctive atmospheres by artificial mixture.
2. The flames of candles and lamps, when they are extinguished by

burning in a confined space of air, produce an atmosphere of almost identical composition with that of air expired from the lungs.

3. The extinctive atmospheres produced by the combustion of the flames of candles and of lamps, and the air expired from the lungs after inspiring fresh air, are respirable with safety.
4. The extinction of an ordinary candle or lamp flame is not necessarily indicative of the unsuitability of an atmosphere to maintain life when it is breathed.

Presents, February 21, 1895.

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